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ABSTRACT

This paper addresses the Space Station Data System (SSDS), the demand on the data system from the user community, how these demands might be accommodated, and some of the technology issues identified that are applicable to the SSDS to meet these demands.

INTRODUCTION

This paper evolves from efforts performed by NASA and industry in recent years that are relevant to current requirements for a Space Station Data System. These efforts include user studies performed on Spacelab[1,2], Science and Application Space Platform[3], Space Platform*[4], and most recently the Space Station Needs, Attributes and Architectural Options Study[5]. The Space Station Data System, as such, has been identified by NASA/Industry as the Key Systerm for a new Manned Space Station in the 1990's. At the Space Station Technology Workshop in Williamsburg in April 1983, one of the primary discussions was how this should be addressed. One of the most complex challenges was to identify the user requirements and implement a SSDS that meets the user's needs, is affordable and allows for an orderly, yet flexible, development and growth.

The User Challenge

Data Acquisition Trends. Improvements in sensor and electronics technology have allowed spacecraft data rates and quantities to increase significantly over the last 20 years. Figure 1 shows this growth trend. The need and capability for improved resolution for earth-viewing imaging sensors is the primary driver of this trend. The high data acquisition rates impact nearly all segments of the end-to-end system -- the space segment, the communication channels, and the ground segment. The slope of this trend may decrease in the future as onboard data compression becomes more practical with further improvements in data processing technology. On the other hand, the acceptability of data compression (and the lost of raw data) is highly dependent on the mission. Science users tend to want to retain all of the raw data that the system is capable of capturing while the other data users may be more willing to accept the processed data product only.

Cost Trends. The cost of ground operations associated with space missions has been growing at a rapid rate. Figure 2 shows this growth trend for a representative set of unmanned spacecraft. This growth rate was approximately 15% per year between 1970 and 1980. A 1978 JPL study placed the annual NASA ground operations costs at $640 million with another $135 million spent for data analysis. This cost growth is due to the increased complexity of the spacecraft being operated and the larger quantities of data being returned, as well as the increasing cost of the labor involved in the ground operations. Because of system complexity and safety concerns, ground operations costs for manned systems are several times the cost of unmanned systems for each day in orbit.

One aspect of cost growth is associated with the changing relationship of hardware and software. As the systems have become more software-intensive, the costs for developing and maintaining the software have become increasingly larger fractions of the total system cost. This trend is shown in Figure 3.

Mission Data Characteristics

The MDAC Space Station Needs, Attributes, and Architectural Options study examined a large set of missions that were potential candidates

*Space Platform is the current program nomenclature which encompasses Space Platform, Power Module, 25 kW Power System, and Science and Application Space Platform.

for utilization of a Space Station. The set was reduced to a smaller set of the 90 most promising missions. (Subsequently, NASA has developed a baseline Space Station mission definition incorporating the MDAC and other mission sets.) This section describes the key data characteristics of this MDAC mission set to the extent that definition was available. While this set of 90 missions is certainly not the same missions that will eventually fly on (or be otherwise accommodated by) the station, it is a representtive set that is useful in understanding the requirements and scope of the end-to-end data system.

Aggregate Data Characteristics. Figure 4 shows the peak and average data rates for the set of missions that are in the MDAC mission data base. Servicing missions were not included as these missions are not expected to place a significant mission-unique demand on the Space Station end-to-end data system. On the right side of the figure the scale shows the average data rate for the plotted missions in bits per day. This characterization of the aggregate set of missions provides some insight into the scope of the mission data but does not provide useful clues as to the instantaneous load on the system since no scheduling information is included. The MDAC mission analysis tested the mission requirements against several system architectures to see what mission accommodation resulted. An example is that an architecture with a manned station at 28-deg inclination and an unmanned platform at 57-deg inclination was assumed and the mission data base was sorted to see which missions could be thereby accommodated. The result was a list of approximately 65 missions. The scheduled operational start and end dates of these missions were used to calculate the aggregate resource demand placed on the Space Station system in each year. Figure 5 shows the result. The lower curve is the aggregate mission average data rate in each year from 1988 to 2004. The individual missions in this aggregate would be divided between the 28-deg station and the 57-deg platform. This is an optimistic (high) estimate in the sense that it was assumed that all candidate missions that could be accommodated in these orbits would be incorporated in the Space Station user community. Lower capture scenarios were also analyzed.

The middle curve in Figure 5 merely shows the peak data rate that could result in each year if all the payloads (missions) were to operate simultaneously at their peak rates. These curves serve to place an upper bound on the data rate/quantity requirement; more work is required to get an adequate requirements base to size the end-to-end system.

Functional Requirement

The functional requirements for a Space Station end-to-end data system are discussed here. The requirements are not exhaustive but are similar to functional requirements of existing systems. They are stated here to provide a framework for later discussions of issues and system concepts.

The functional requirements are presented in three categories: (1) those data-related functions which are necessary to make the Space Station useful to a mission user, (2) those functions that are related to operating the station, and (3) requirements that are derived from overall system goals such as cost-effectiveness and flexibility. These requirements are presented in Tables 1, 2, and 3, respectively.

Architectural Concepts

Some preliminary concepts and considerations for the end-to-end data system architecture are presented. A basic concept for consideration is that of providing a high degree of function relocatability so that the system is highly adaptable to configuration changes and operating requirement changes. Function relocatability will cause the overall system to have excess capacity in some respects. However, the rapid rate of advance in the data processing technology should make the capacity and flexibility possible to implement a system wherein major functions can be shifted among the system nodes.

User Support Concepts

Several concepts have been defined that can be used as guidelines in the end-to-end system development. These concepts include (1) classification of users into standard categories, (2) development of a set of standard services and interfaces for users, and (3) implementation of a level of user service that supports most user needs with users taking responsibility for implementing unique capabilities that lie beyond this level.

Table 4 discusses the classification of users and lists some factors that are important in classifying users according to their impact on the Space Station.

An important concept is that of service and interface standarization. Standardization is important in minimizing user costs, in minimizing premission user integration activities and schedule, and in enabling an effective on-orbit user integration. Table 5 lists some of the standard services that should be defined for users. These include not only the on-orbit services such as power, thermal, control, and pointing interfaces, crew support, and communications, but permission services such as integration planning and testing and crew training.

In developing the end-to-end system and the related user service level definition, the attempt should be made to meet user needs but to not allow unique user requirements to drive the design. In other words, a driving requirement that provides a service that is needed by only one or two potential users should probably not be implemented in the core Space Station system. Instead, these few unique requirements should be implemented by the user. Table 6 summarizes this concept.

Figure 6 is a conceptual view of the user mission services that would be provided by the end-to-end data system, the user interfaces with the system, and the internal interfaces and data flows between the system functions.

Simplified Model of End-to-End Data System

A simplified model of the end-to-end data system is shown in Figure 7. It is implicit that many of the resources in the system will be shared by numerous users. However, each user will want the maximum autonomy available. The figure shows typical functions that are performed in the system.

Technology Needs and Opportunities

Table 7 lists some of the key technology needs for a Space Station end-to-end data system that will meet user needs at affordable costs.

A major need associated with high-speed communications is recording technology. The use of optical recording offers a promising solution. Currently, optical recording is in the prototyped stage with recording densities of 10^9 bits per square inch giving storage capacities up to 6.25 Gbytes on a 12-inch platter. These platters are nonerasable. Should this technology be employed in space, recording densities of up to 10^{10} bits per square inch with erase capabilities will be necessary. Equally important, the recordng disk must be capable of surviving launch and must provide for automatic correction for any platter distortion. Optical recording technology offers some potential advantages for launch survivability as head to platter distances are greater and warpage is of significantly less importance than for magnetic disks; further development of mechanical design is required. Optical recording also has great potential benefit for ground segment applications. Table 8 summarizes the current status and project Space Station requirements for optical data storage.

The technology of automation is being developed quite independent of space applications. Monitoring, decision-making, and control are being performed automatically at higher speeds than the human is capable. The human operator is becoming an overseer on call to correct the unexpected and to provide maintenance as required. Automation can be applied to both space and ground systems with the same change in the traditional role of the human operator and, therefore, the number of operators. The technology needs associated with space automation principally involve the design for specific applications, as for example, the monitoring of a telemetry data stream to compare these data with expected state data derived from previous commands. The development of analytical tools, principally software, that will allow a machine to rapidly diagnose failures or malfunctions is another area requiring development. For example, given knowledge that a particular bilevel event as indicated by telemetry is in error, the logic must be developed that will analyze probable causes and select the preferred command corrections from predefined set of alternatives, much the same as human operator would do.

If high data rate space-to-space links are employed, then development is required for either laser or millimeter wavelength systems. In particular, 5 to 7 year lifetimes are required. Rapid and reliable automatic acquisition is required for beamwidths that support 10^9 and 10^{10} bps. Much of this technology has been developed, as for example, the K-band tracking radar on the Shuttle. If lasers are employed, further development on laser lifetime and detector array fabrication is required.

ACKNOWLEDGEMENT

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FIGURE 1

VGB262

DATA ACQUISITION TRENDS

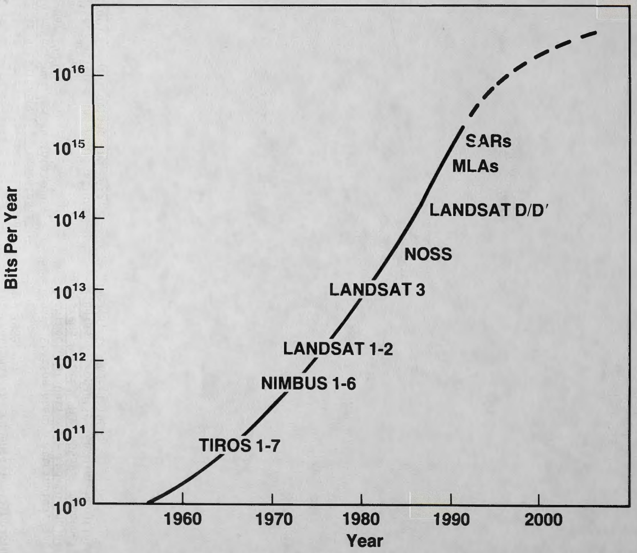

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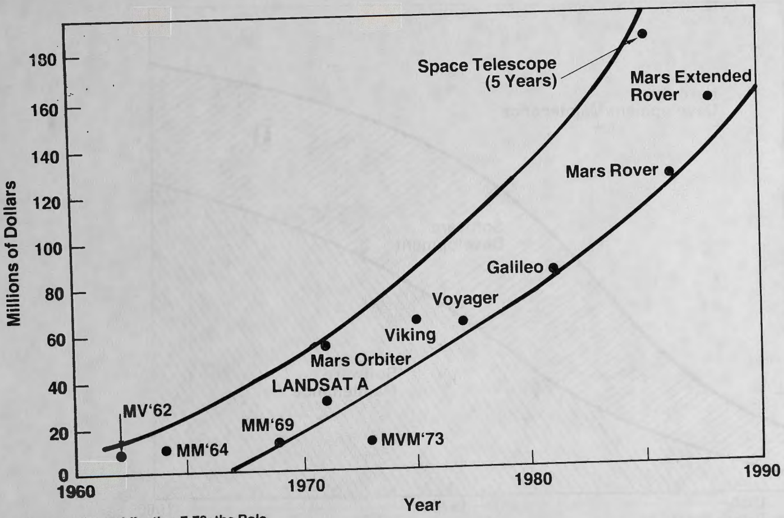
FIGURE 2

VGB263

TREND OF MISSION GROUND OPERATION COST

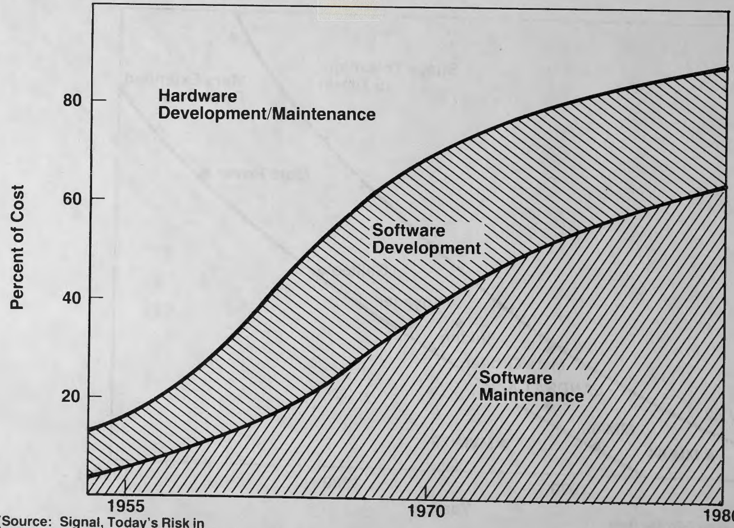


Source: JPL Publication 7-78; the Role of Robots and Automation in Space; E. Heer, Sep 1, 1978

FIGURE 3

VGB264

TREND OF SOFTWARE/HARDWARE COST RELATIONSHIP FOR DOD PROGRAMS



(Source: Signal, Today's Risk in Software Development, Bunyard and Coward, October 1982)

FIGURE 4

PEAK AND AVERAGE RATES FOR THE SPACE STATION MISSIONS

VGB265

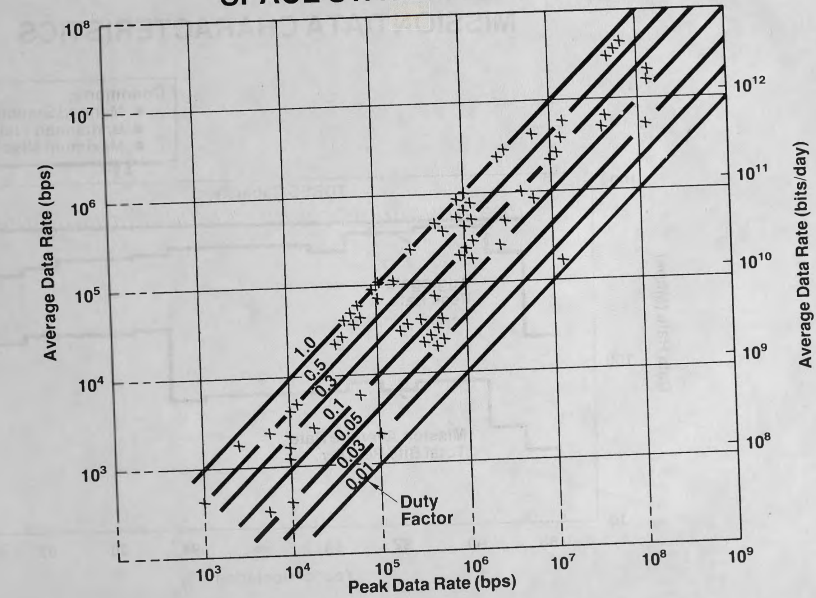


FIGURE 5

MISSION DATA CHARACTERISTICS

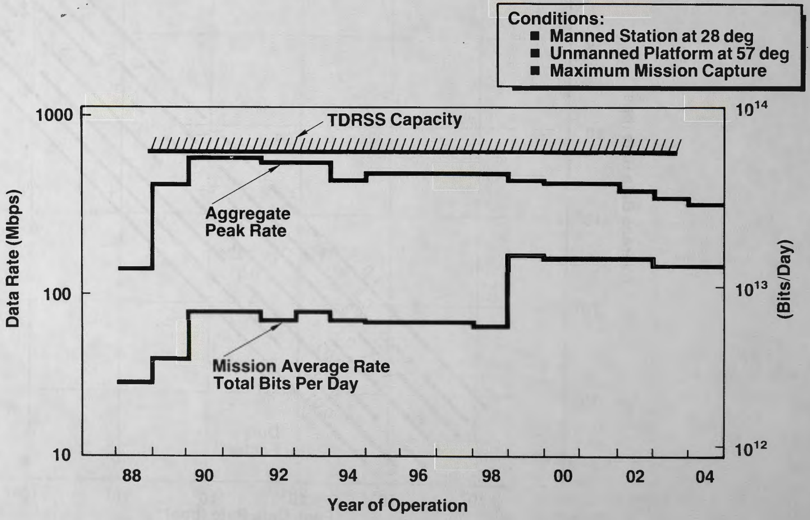


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FIGURE 6

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USER CONCEPTS

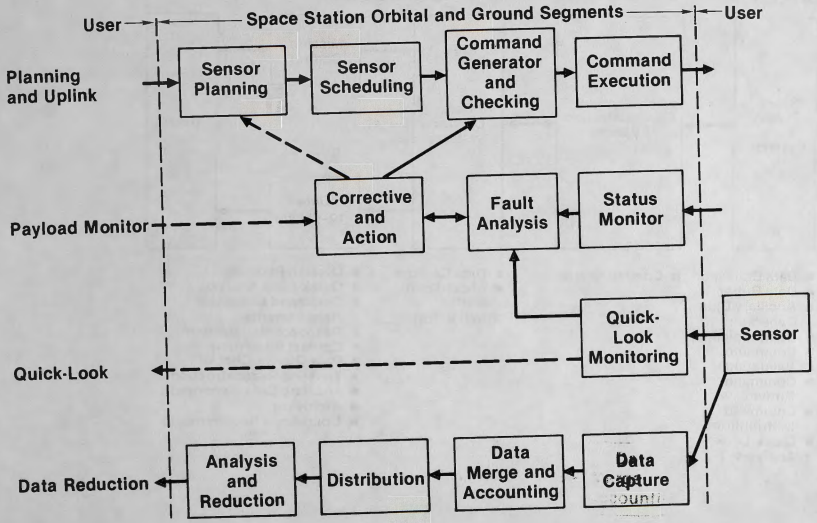

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FIGURE 7

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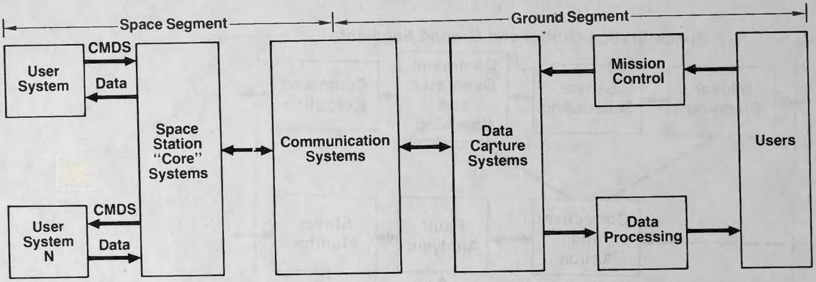
SIMPLIFIED MODEL OF END-TO-END DATA SYSTEM



- Command Implementation
- Data Acquisition
- Signal Conditioning

- Data Collection
- Data Buffer
- Ancillary Data Generator
- Communication
- Command Validation
- Command Buffer
- Command Distribution
- Quick-Look Analysis

- Communication

- Data Capture
- Short-Term Buffer
- Initial Sorting

- Mission Planning
- Quick-Look Analysis
- Command Generator Requirements
- Resource Management
- Conflict Resolution
- Data Quality Checks
- Timeline Reconstruction
- Ancillary Data Generation
- Archiving
- Operations Requirements

Table 1

END-TO-END DATA SYSTEM

USER-RELATED REQUIREMENTS

- CAPTURE MISSION DATA
- PROVIDE COMMAND, CONTROL, AND STATUS-MONITOR CAPABILITY
- PROVIDE MISSION-SUPPORTING ANCILLARY DATA
- PROVIDE DATA PROCESSING NECESSARY TO FURNISH USABLE DATA PRODUCTS
- PROVIDE SHORT-TERM ARCHIVING OF MISSION DATA
- PROVIDE TIMELY DISTRIBUTION OF DATA TO USERS
- PROVIDE CAPABILITY FOR USER DATA PRIVACY
- PROVIDE COMMUNICATIONS CAPABILITY (INCLUDING MANAGEMENT OF COMMERCIAL AND INSTITUTIONAL RESOURCES)
- PROVIDE CAPABILITY FOR REAL-TIME INTERACTION BETWEEN FLIGHT CREW, GROUND CREW, AND MISSION EQUIPMENT
- PROVIDE INFORMATION AND RESOURCES TO SUPPORT MISSION PLANNING
- PROVIDE CAPABILITY TO SUPPORT MISSION INTEGRATION ACTIVITIES

Table 2

END-TO-END DATA SYSTEM

SPACE STATION RELATED REQUIREMENTS

- PROVIDE COMMAND, CONTROL, AND STATUS MONITORING CAPABILITY FOR SUBSYSTEMS
- PROVIDE DATA ENTRY, PROCESSING, DISPLAY, AND STORAGE CAPABILITY TO SUPPORT ONBOARD CREW FUNCTIONS
- PROVIDE DATA PROCESSING CAPABILITY TO SUPPORT SUBSYSTEM OPERATION, MAINTENANCE, AND RECONFIGURATION
- PROVIDE COMMUNICATIONS RESOURCES TO SUPPORT CREW ACTIVITIES AND STATION OPERATIONS
- PROVIDE CAPABILITY TO SUPPORT SHORT AND LONG TERM MISSION PLANNING
- PROVIDE CAPABILITY TO SUPPORT PRELAUNCH AND ORBITAL INTEGRATION ACTIVITIES
- PROVIDE CAPABILITY TO OPERATE SPACE STATION IN AN UNMANNED MODE

Table 3

END-TO-END DATA SYSTEM

GENERAL REQUIREMENTS AND GOALS

- SUPPORT EFFECTIVE USE OF ONBOARD CREW
- MINIMIZE REQUIREMENTS FOR GROUND OPERATIONS STAFF
- ACCOMMODATE INCORPORATION OF NEW SYSTEM ELEMENTS AND MISSION EQUIPMENT THROUGHOUT THE SYSTEM LIFETIME
- INDEFINITE LIFETIME WITH MAINTENANCE AND SYSTEM UPGRADES
- MINIMIZE USER DATA DELIVERY TIME
- MINIMIZE USER INTEGRATION COST, SCHEDULE, COMPLEXITY, ETC.
- BE COMPATIBLE WITH EXISTING FACILITIES AND RESOURCES (E.G., TDRSS), BUT BE CAPABLE OF ACCOMMODATING UPGRADED OR NEW FACILITIES

Table 4

CLASSIFICATION OF USERS

ASSUMPTION

- USER TRAFFIC MODEL IS REPRESENTATIVE SAMPLE OF FUTURE POPULATION
- SPACE STATION SHOULD BE PREPARED FOR ALL

CONCEPT

- CLASSIFICATION OF USERS INTO STANDARD CATEGORIES
- DELIMITERS, FOR EXAMPLE:
    - IMAGING/NONIMAGING
    - DATA RATE, AMOUNT
    - FILL/DUMP REQUIREMENT
    - REAL-TIME INTERACTION REQUIREMENT
    - COMPLEXITY OF PLANNING CYCLE
    - DEPENDENCE ON OTHER ELEMENTS

Table 5

STANDARD SERVICES FOR USERS

ASSUMPTION

- COST OF PROJECT IMPORTANT TO USER

CONCEPT

- DEVELOP A SET OF COMPREHENSIVE STANDARD SERVICES FOR EACH USER CLASS
  - ATTACHED SERVICES
    - POWER, THERMAL, POINTING, ETC.
  - STANDARD USER INTEGRATION SERVICES
  - STANDARD REPAIR/REFURBISHMENT SERVICES
  - STANDARD TRAINING/CREW ACTIVITIES SERVICES
  - STANDARD COMMUNICATIONS SERVICES
  - STANDARD REPAIR MODULES, SUBSYSTEMS AND PARTS
  - STANDARD CONTROL SERVICES
  - STANDARD DATA CAPTURE, DISTRIBUTION SERVICES

Table 6

MOST SUPPORT TO THE MOST USERS

PRINCIPLE

CONFIGURE TO SUPPORT THE VAST MAJORITY OF USERS. DO NOT LET "UNIQUE" OR "OUTSIDE-THE-ENVELOPE" REQUIREMENT DRIVE OVERALL DESIGN

COMMENTS

- ALLOWS TECHNOLOGY LIMITS TO BE APPLIED WITHOUT KILLING PROGRAM
- MULTIPLE LEVELS OF SERVICE MAY ALLEVIATE TOUGH USER PROBLEMS
- ALLOWS SELECTABLE LEVELS OF SERVICE TO GOVERN COST/CAPTURE RATIO CURVES FOR USERS
- UNIQUE USERS GET UNIQUE SYSTEMS AT UNIQUE PRICES

Table 7

TECHNOLOGY NEEDS - END-TO-END DATA SYSTEMS

- ONBOARD MASS DATA STORAGE
  - COMMUNICATIONS BUFFER
  - DATA ARCHIVE
- GROUND-BASED MASS DATA STORAGE
- RECONFIGURABLE SOFTWARE
- AUTOMATION/AUTONOMY TECHNIQUES
  - EXPERT SYSTEMS
  - AUTOMATED SUBSYSTEMS MANAGEMENT
  - AUTOMATED MISSION PLANNING AND SCHEDULING
- SOFTWARE LANGUAGES AND DEVELOPMENT TOOLS
- ADVANCED SPACE-TO-GROUND AND SPACE-TO-SPACE COMMUNICATIONS

Table 8

OPTICAL RECORDING TECHNOLOGY

CURRENT

10^9 BITS/IN^2

6.25 G BYTES (WITH OVERHEAD)

12 INCH PLATTER

PROTOTYPE

NON-ERASABLE

REQUIREMENTS (1990)

10^{11} BITS/IN^2

700 G BYTES STORAGE CAPACITY

ERASABLE

OPERATIONAL

LAUNCH SURVIVABLE

AUTOMATIC CORRECTION FOR PLATTER DISTORTION